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TITLE: INFILTRATION AT YUCCA MOUNTAIN, NEVADA, TRACED BY CHLORINE-36

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INFILTRATION AT YUCCA MOUNTAIN, NEVADA, TRACED BY ^{36}CL

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Measurements of chloride and ^{36}Cl in soils from two locations near Yucca Mountain, Nevada, have been used to trace the infiltration of precipitation in this arid region. The results show that the ^{36}Cl fallout from nuclear weapons testing formed a well-defined peak at one location, with a maximum 0.5 m below the surface. The structure of the ^{36}Cl bomb pulse at the other location was much more complex, and the quantity of ^{36}Cl in the bomb pulse was <1% of the 6×10^{12} atoms ^{36}Cl/m^2 in the bomb pulse at the first location. The data indicate hydrologic activity subsequent to the ^{36}Cl bomb pulse fallout at one location, but none at the other location.

1. Introduction

Yucca Mountain, Nevada, is one of three candidate sites currently being characterized by the U. S. Department of Energy for possible use as a high level nuclear waste repository [1]. The rate of water movement through the unsaturated volcanic rock in which the canisters containing the radioactive wastes would be emplaced is an important parameter in assessing the repository performance. One source of water in the unsaturated zone is the infiltration of precipitation. This study was undertaken to help quantify the infiltration.

Nuclear weapons testing conducted at sea level in the Pacific Ocean from 1952 through 1963 produced ^{36}Cl by the ^{35}Cl(n,γ) reaction in seawater. High yield tests injected large amounts of ^{36}Cl into the stratosphere. The ^{36}Cl was distributed globally as a pulse of fallout. Trotman [2] showed that this bomb pulse of ^{36}Cl could be used to characterize infiltration into sandy loam near Socorro, New Mexico. We wanted to obtain similar information at the site of the Yucca Mountain exploratory shaft. However, both the topography and measurements of the chloride contents of soils from a trench near the exploratory shaft site suggested that active hydrologic processes occur in this location. Therefore, we chose to measure in addition the ^{36}Cl bomb pulse distribution at a location in Yucca Wash about 4 km east of the exploratory shaft site. The Yucca Wash site was selected because of the presence of desert varnish and the high chloride content of the soil, which indicated geomorphic stability and the long-term accumulation of salts. The Yucca Wash site appeared to be one where the entire ^{36}Cl bomb pulse could be measured.

2. Measurements and Results

Soil horizons at the two locations selected near Yucca Mountain were sampled to determine chloride and $^{36}Cl/Cl$ distributions as functions of the depths of the samples from the land surface. Samples at the Yucca Wash site (36°52'N, 116°25'W) were collected from a trench that had been dug approximately one year earlier. Samples at the exploratory shaft site (36°51'N, 116°27'W) were collected immediately after a bulldozer excavated a trench. In both cases, hand tools were used to scrape samples from the trench walls. Sampling commenced at the bottom of the trenches and worked up, to prevent contamination of samples by material sloughing from above.

The samples collected from the trenches were transported to a laboratory, where they were prepared for chloride and ^{36}Cl measurements. The preparations consisted of drying each soil sample in an oven; weighing the sample; contacting the dried soil with distilled, deionized water; and filtering the resulting slurry—after settling—through a 0.45μ filter. Each filter was rinsed before use to minimize the introduction of chloride contamination into the sample, as Jay [3] recommended.

Chloride analyses were performed on aliquots of the filtered solutions, using the standard mercuric nitrate titration method [4]. The results are listed in Table 1, column 3. Samples numbers in the table preceded by Y are from Yucca Wash; those preceded by E are from the exploratory shaft site.

The solution remaining from each sample was used to prepare a AgCl precipitate for ^{36}Cl analysis at the University of Rochester's tandem accelerator. Reagent grade $AgNO_3$ was placed in the solution to precipitate at least 200 mg AgCl. The precipitate was filtered, washed, and treated twice with NH_4OH and a solution of $Ba(NO_3)_2$ to remove sulfur. The resulting AgCl precipitate was analyzed for ^{36}Cl, using the method of Elmore et al. [5]. The measured $^{36}Cl/Cl$ ratios are listed in Table 1, column 4. The uncertainties are the 1σ values derived from the counting statistics.

Plots of the $^{36}Cl/Cl$ ratios as a function of the sample depth are shown in Figure 1. Soil types and observed soil horizons are delineated at the right of each plot. The soil types at the Yucca Wash site are those given by Taylor [6].

The ^{36}Cl derived from the bomb pulse was calculated for each site. First, the measured $^{36}Cl/Cl$ ratios were corrected for the cosmogenic background of ^{36}Cl by subtracting 519×10^{-15}, which is the weighted mean of the $^{36}Cl/Cl$ values for samples Y1, E1, and E2 in Table 1. Then the $^{36}Cl/Cl$ ratios were converted to ^{36}Cl atoms/m^3 through the use of the measured mg Cl/kg soil and an assumed soil density of 2 g/10^{-6} m^3. These data are listed in the last column of Table 1. Finally, the data were integrated with a computer program that used the AVINT subroutine [7]. The bomb pulse derived from the Yucca Wash data in the interval from 0.16 m to 1.43 m is $(6.0\pm1.1)\times10^{12}$ atoms $^{36}Cl/m^2$.

The exploratory shaft site data, integrated from 0.19 m to 1.57 m, yield $(4.5\pm2.3)\times10^{10}$ atoms $^{36}Cl/m^2$ as the bomb pulse. The uncertainties in each case were derived from a propagation of errors calculation.

3. Discussion

The data collected in this work provide information about the infiltration of precipitation at two sites near Yucca Mountain, Nevada. At Yucca Wash, the generally increasing chloride concentrations with depth in the soil is evidence for downward flow, while the high chloride concentration shows slow solute movement. The clearly defined peak in the $^{36}Cl/Cl$ distribution indicates low hydrodynamic dispersion and, at the scale of the sampling, a relatively homogeneous flow system. Small dispersivities and homogeneous flow are characteristic of the low velocities encountered in unsaturated flow conditions in fine grained materials. The average velocity of water flow in the soil can be calculated from the position of the ^{36}Cl bomb pulse peak as 1.8×10^{-2} m/yr. If the volumetric water content of the soil is taken to be 10%, then the average infiltration rate is 1.8×10^{-3} m/yr. However, the peak of the bomb pulse coincides with a change in soil texture. The concept of average infiltration may be inapplicable in this case.

The data from the exploratory shaft site contrast sharply with those from the Yucca Wash site. The chloride contents of the exploratory shaft site samples in the first 1.5 meters below surface are at least an order of magnitude lower than those measured at the Yucca Wash site. The exploratory shaft site chloride concentrations increase dramatically below 1.5 m. This chloride profile can be interpreted as a shallow, hydrologically active zone overlying a relatively stagnant region. The increase in chloride concentration does not occur at a location characterized by a change in soil texture. The $^{36}Cl/Cl$ ratios in the exploratory shaft site soil show large fluctuations over small changes in depth (see Figure 1). These data indicate hydrologic activity subsequent to the deposition of the ^{36}Cl bomb pulse. The ^{36}Cl bomb pulse integrals corroborate this interpretation of recent hydrologic activity at one site, but not at the other. The exploratory shaft site integral is only 0.7% that of the ^{36}Cl bomb pulse at the Yucca Wash site. The ^{36}Cl that should have been observed in the bomb pulse at the exploratory shaft site presumably was washed away.

The ^{36}Cl bomb pulse observed at the Yucca Wash site, which appears to include the entire pulse, can be compared with the three measurements of the ^{36}Cl bomb pulse reported by others. Elmore et al., [8] measured the ^{36}Cl bomb pulse in an ice core from Greenland. They reported 1.3×10^{12} atoms $^{36}Cl/m^2$. The curve for the variation of meteoric ^{36}Cl fallout with latitude in ref. [9] was used to convert this integral to a value of 4.4×10^{12} atoms $^{36}Cl/m^2$ at the Yucca Wash latitude. Bentley et al., [10] reported the ^{36}Cl bomb pulse in subsurface water at the Borden Canadian Forces Base to be 5.75×10^{12} atoms $^{36}Cl/m^2$. The third reported value does not agree with the other results. Trotman [2] reported an integral of 7.4×10^{11} atoms $^{36}Cl/m^2$ for the bomb pulse in sandy loam near Socorro, New Mexico. The reason for the lower bomb pulse integral at Socorro, in comparison to the other results, is not known.

The ^{36}Cl fallout from nuclear testing activities at Yucca Mountain could be a composite of global fallout plus local fallout from the adjacent Nevada Test Site. The $^{240}Pu/^{239}Pu$ ratio in soil samples collected to a depth of ~3 cm both at Yucca Wash and at the crest of Yucca Mountain were measured to determine the extent of local fallout. The $^{240}Pu/^{239}Pu$ ratios of 0.033 at Yucca Wash and 0.032 at the crest of Yucca Mountain are indicative of local fallout. The ratio for global fallout is 0.176 [11]. Any deviation from global fallout in the ^{36}Cl bomb pulse at Yucca Mountain arising from local testing is likely to be small, however, because atmospheric testing was conducted almost always when the wind direction was from Yucca Mountain, rather than toward it, and because the Nevada tests, unlike those in the Pacific Ocean, did not have a large source of chlorine available for the production of ^{36}Cl by neutron activation of ^{35}Cl. The two sites investigated in this work are sufficiently close to one another that the ^{36}Cl bomb pulse should have been the same at each, regardless of local testing activities.

Acknowledgements

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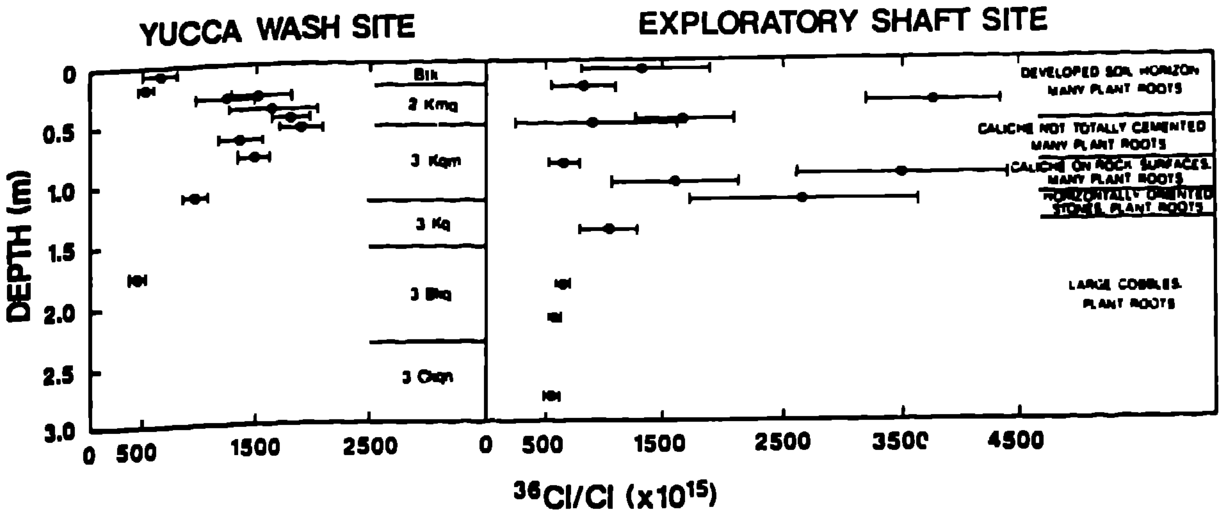
Figure 1 caption:

$^{36}Cl/Cl$ ratios with depth at the Yucca Wash site (left) and at the exploratory shaft site (right). Soil horizons and soil types are indicated at the right of each plot.

Table 1 caption:

Results of Chloride and ^{36}Cl analyses

Sample Number	Depth Interval Below Surface (m)	$\frac{\text{mg Cl}}{\text{kg soil}}$	$\frac{^{36}Cl}{Cl}$ ($\times 10^{15}$)	$\frac{\text{net atoms } ^{36}Cl}{m^3}$
Y15	0.000-0.152	22.0	646±159	9.49×10^{10}
Y14	0.152-0.229	31.8	528±69	9.72×10^{9}
Y13	0.229-0.259	28.4	1531±312	9.76×10^{11}
Y12	0.259-0.305	75.5	1239±288	1.85×10^{12}
Y11	0.335-0.411	451.1	1646±398	1.73×10^{13}
Y10	0.427-0.488	477.3	1818±168	2.11×10^{13}
Y9	0.518-0.549	60.7	1904±183	2.86×10^{12}
Y7	0.610-0.640	96.1	1360±204	2.75×10^{12}
Y5	0.762-0.792	178.6	1479±132	5.82×10^{12}
Y3	1.067-1.158	277.1	954±100	4.10×10^{12}
Y1	1.707-1.829	973.6	455±64	—
E15	0.000-0.152	—	1352±549	—
E14	0.152-0.305	1.2	839±278	1.30×10^{10}
E13	0.305-0.396	1.2	3821±583	1.35×10^{11}
E12	0.457-0.549	2.5	1700±427	1.00×10^{11}
E11	0.488-0.579	2.1	922±697	2.88×10^{10}
E8	0.823-0.914	1.5	673±123	7.85×10^{9}
E7	0.914-1.006	0.5	3543±900	5.14×10^{10}
E6	0.975-1.097	0.5	1616±539	1.86×10^{10}
E5	1.128-1.219	0.5	2700±975	3.70×10^{10}
E4	1.372-1.463	1.6	1046±250	2.86×10^{10}
E3	1.798-1.920	166.7	645±52	7.14×10^{11}
E2	2.073-2.225	503.9	531±41	—
E1	2.743-2.835	637.5	557±67	—


YUCCA WASH SITE
EXPLORATORY SHAFT SITE
DEPTH (m)
0
0.5
1.0
1.5
2.0
2.5
3.0
0 500 1500 2500
0 500 1500 2500 3500 4500
$^{36}Cl/Cl$ (x10^{15})
DEVELOPED SOIL HORIZON
MANY PLANT ROOTS
CALICHE NOT TOTALLY CEMENTED
MANY PLANT ROOTS
CALICHE ON ROCK SURFACES,
MANY PLANT ROOTS
HORIZONTALLY ORIENTED
STONES, PLANT ROOTS
LARGE COBBLES,
PLANT ROOTS